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Regelsberger et al.

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(54) **DRIVE GEARS PROVIDING IMPROVED REGISTRATION IN DIGITAL PRINTING SYSTEMS**

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B41J 2/01 (2006.01)
B41J 15/02 (2006.01)

(52) **U.S. Cl.**
CPC ***B41J 15/02*** (2013.01)

(58) **Field of Classification Search**
USPC 347/152, 154, 212, 213, 218, 174, 104, 347/19, 16; 400/578
See application file for complete search history.

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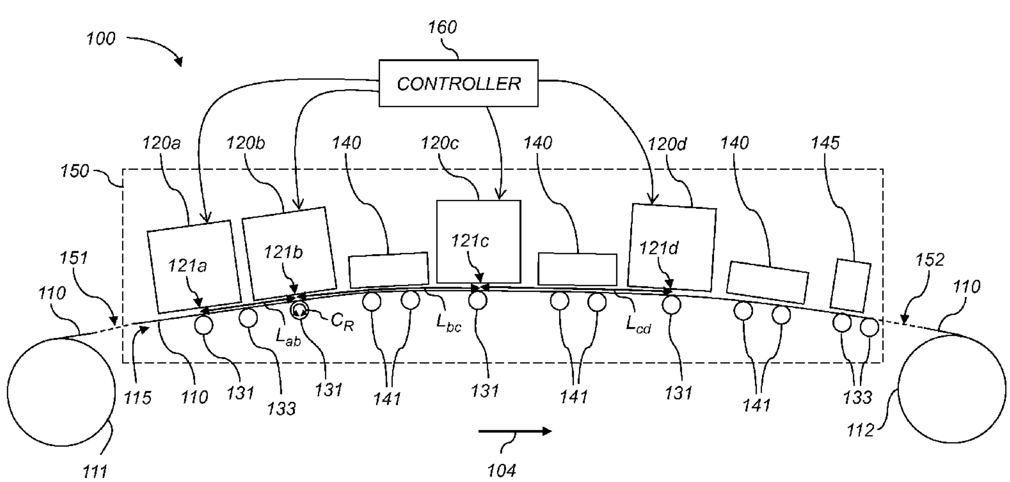
(57) **ABSTRACT**

A printing system for printing on a web of media traveling along a web transport path, including a plurality of printheads for printing on the web of media, each of the printheads being configured to print at one or more corresponding print locations along the web transport path. A plurality of web transport rollers guide the web of media along the web transport path. A drive roller causes the web of media to move along the web transport path. The drive roller has an affixed driven gear driven by a motor using a gear train including one or more drive gears which transfer torque from the motor to the driven gear. The driven gear and the drive gears are constrained to rotate substantially an integer number of times as the web of media is advanced along the web transport path between two successive print locations.

23 Claims, 10 Drawing Sheets



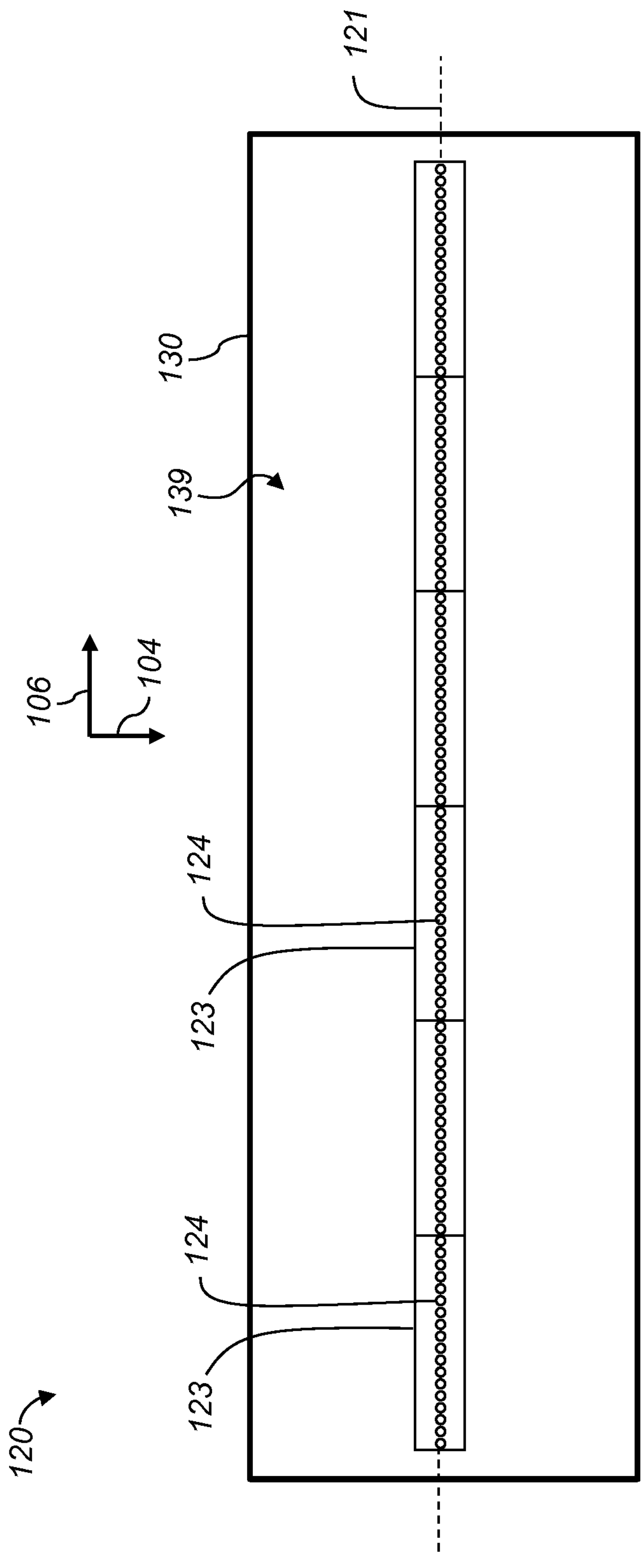
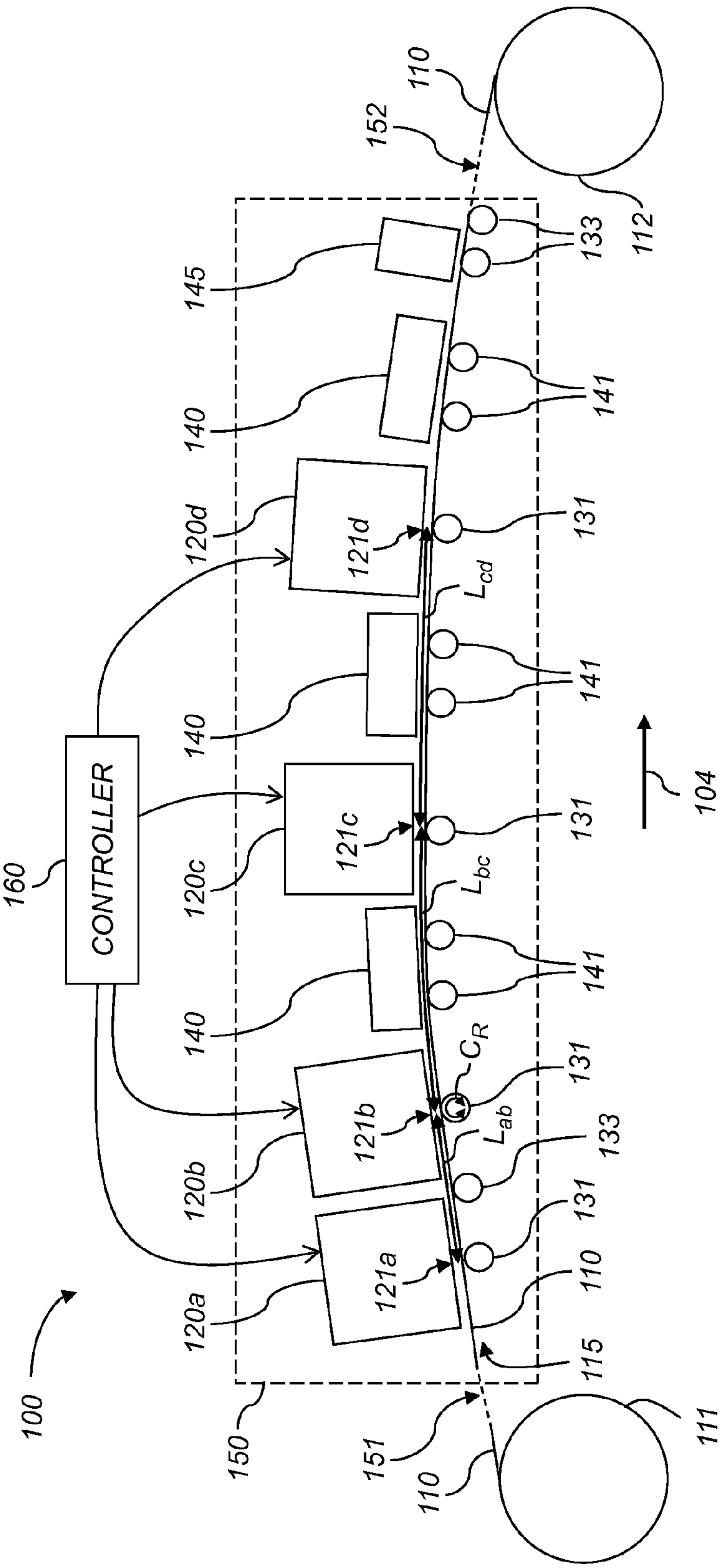


FIG. 1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CONTROLLER
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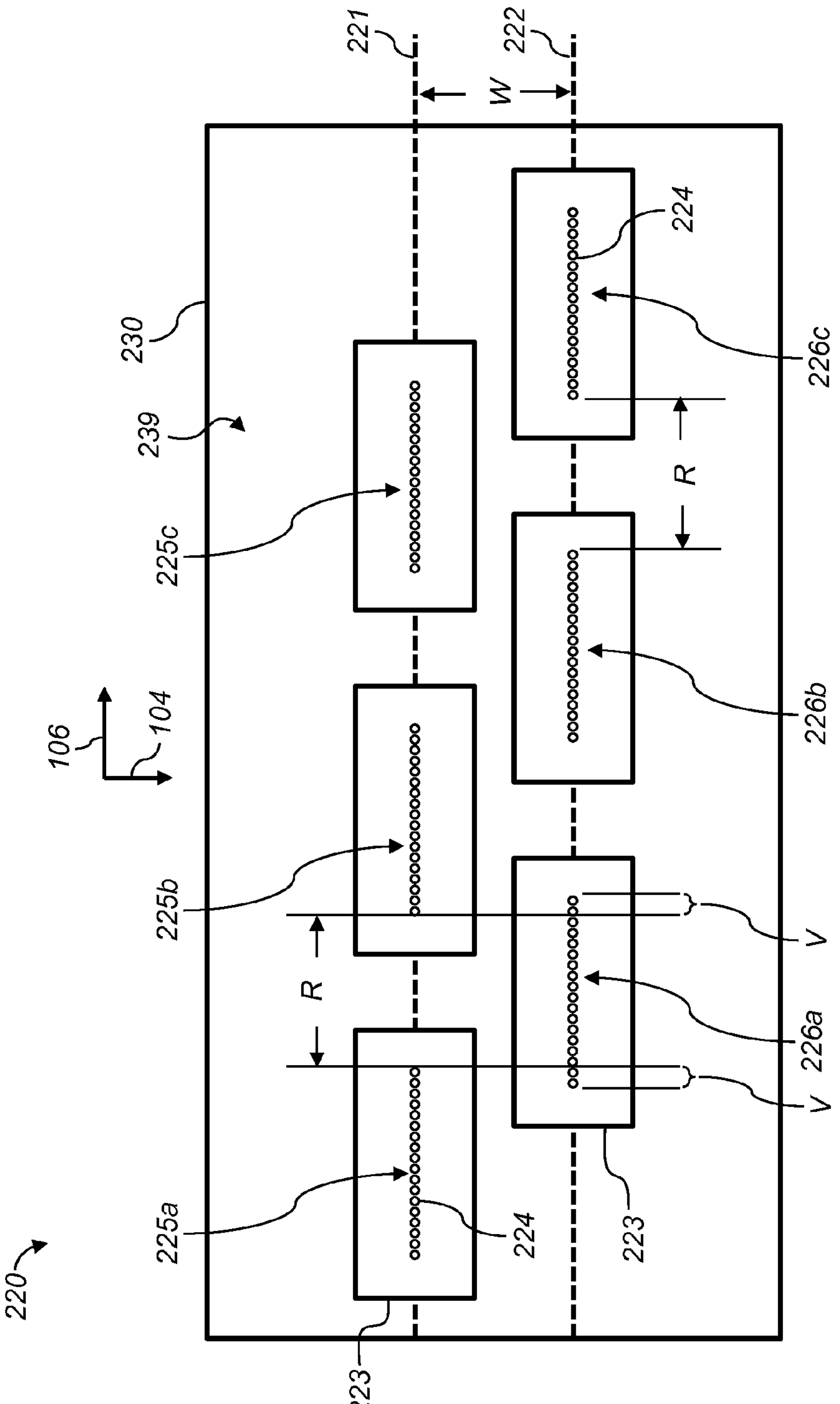
150
110
111
112
115
151
152
120a
120b
120c
120d
121a
121b
121c
121d
131
133
140
141
145
L_{ab}
L_{bc}
L_{cd}
C_R
104

FIG. 2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222
W
230
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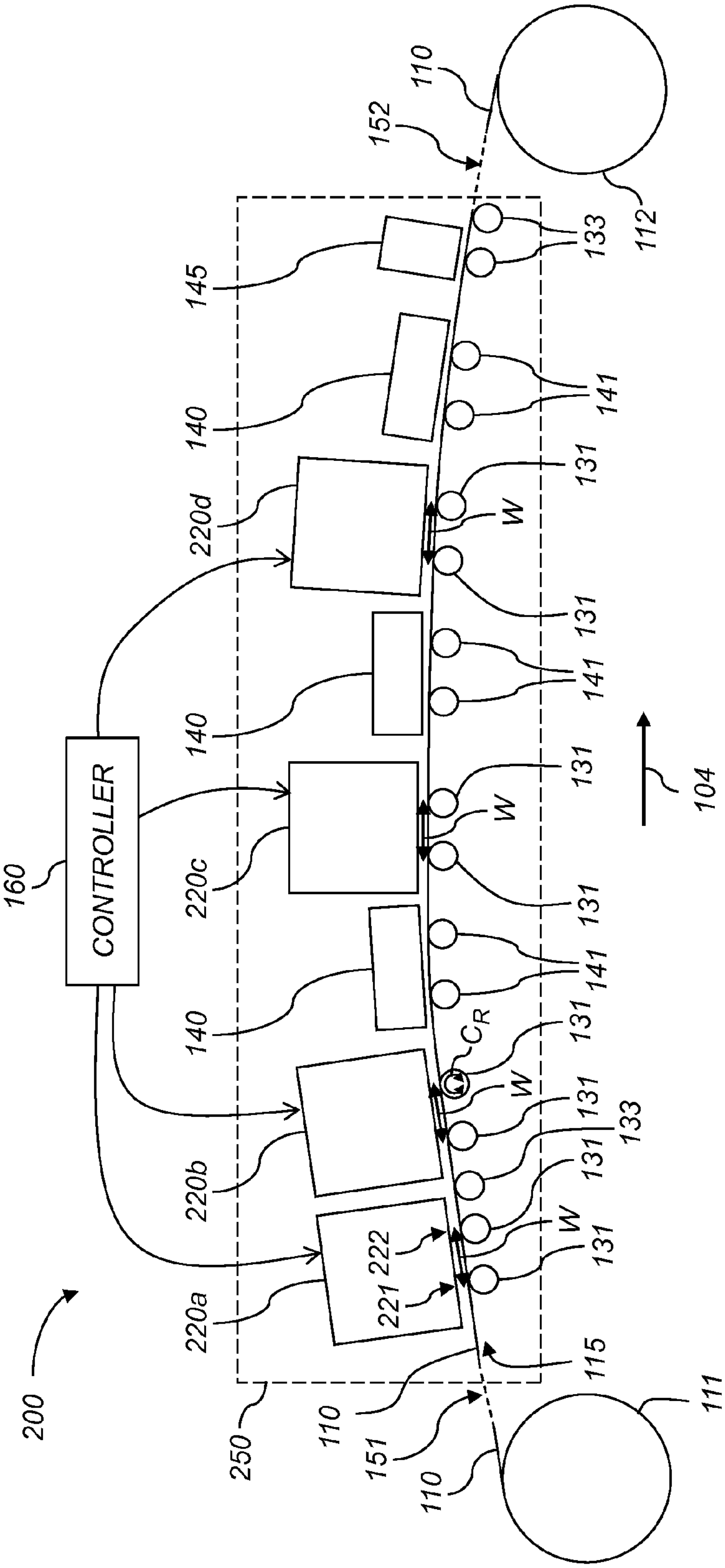
104
226b
225b
V
226a
225a
223
220

FIG. 3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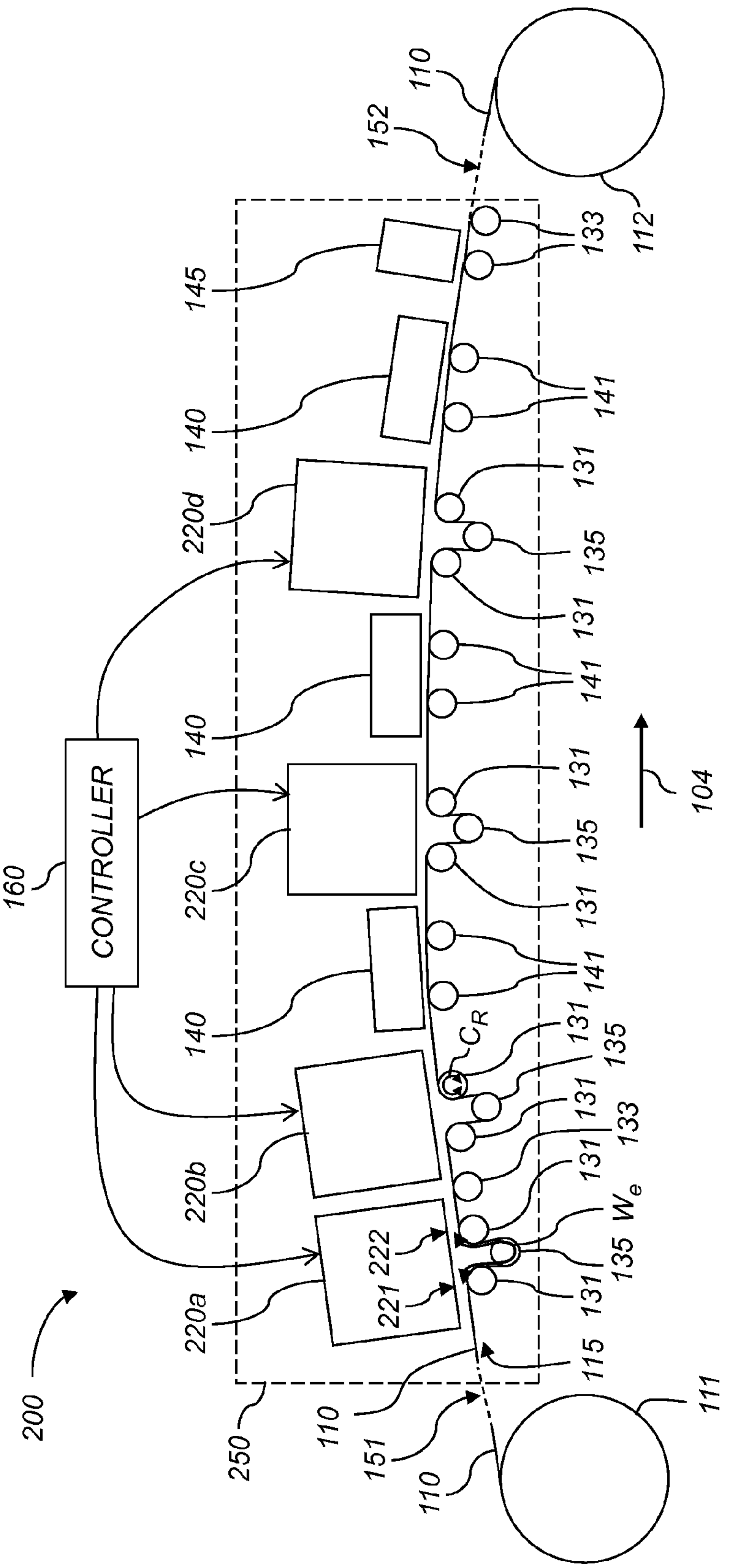
110
111
112
115
151
152
104

FIG. 4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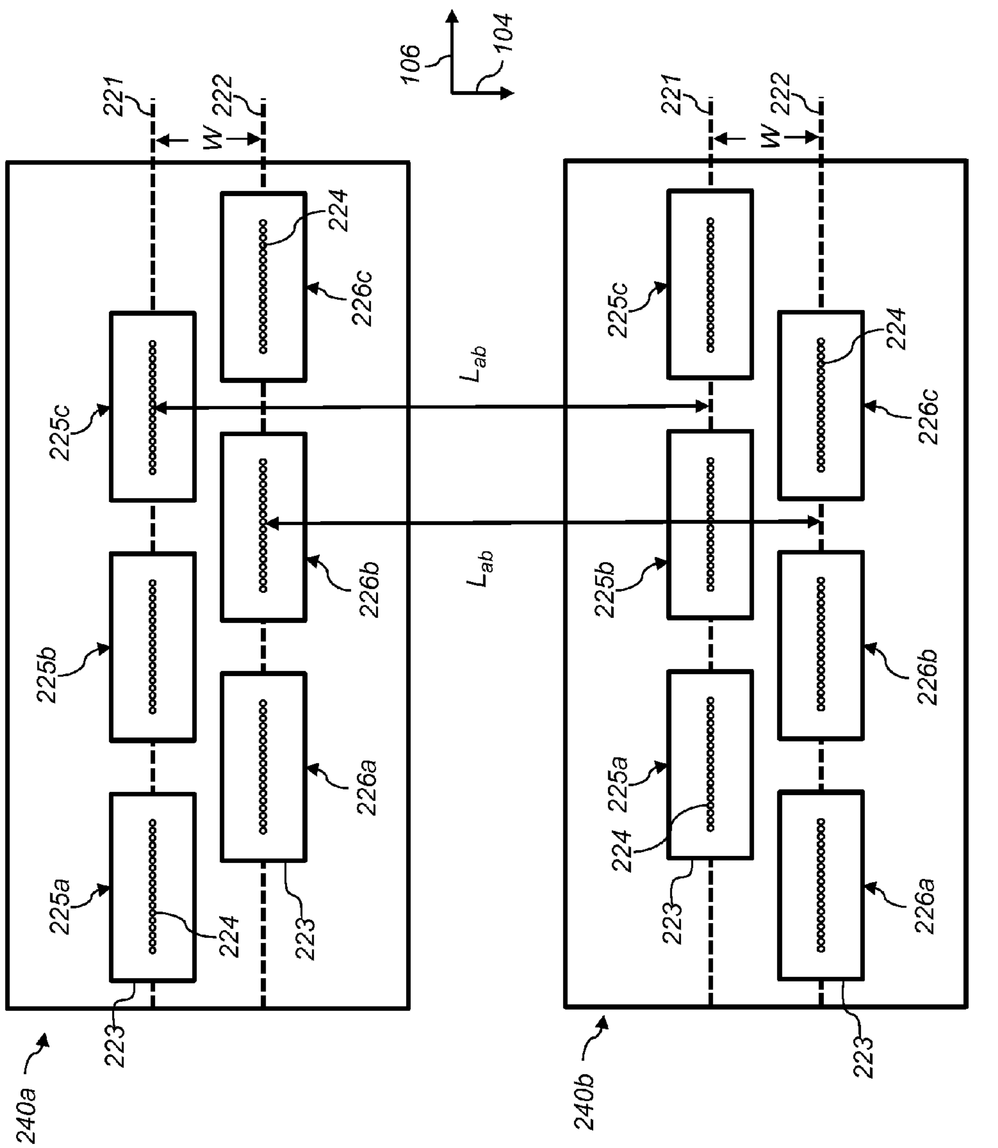
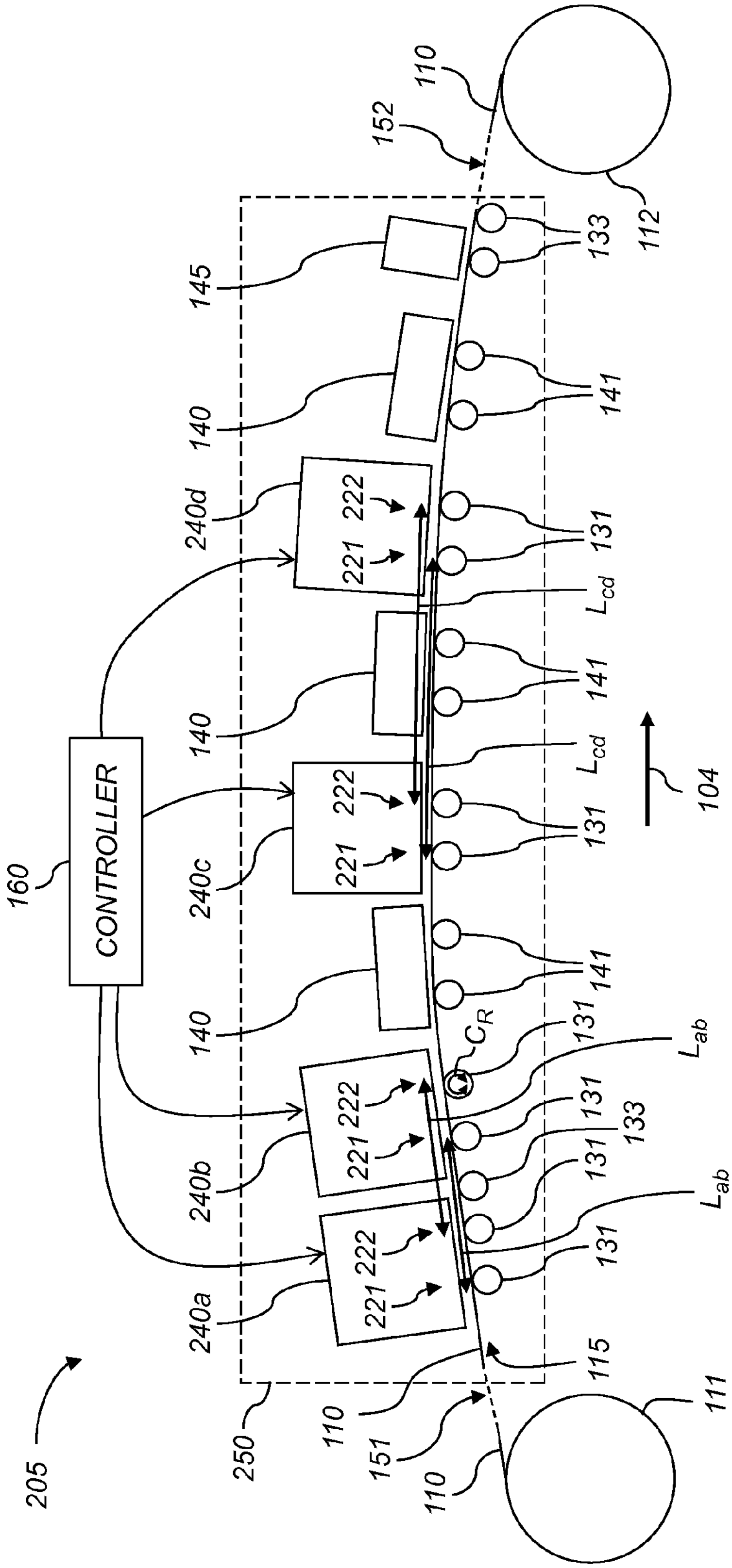
152
131
133
135
141
C_R
W_e
104

FIG. 5



106
104
221
222
W
224
225a
225b
225c
226a
226b
226c
223
L_{ab}
240a
240b

FIG. 6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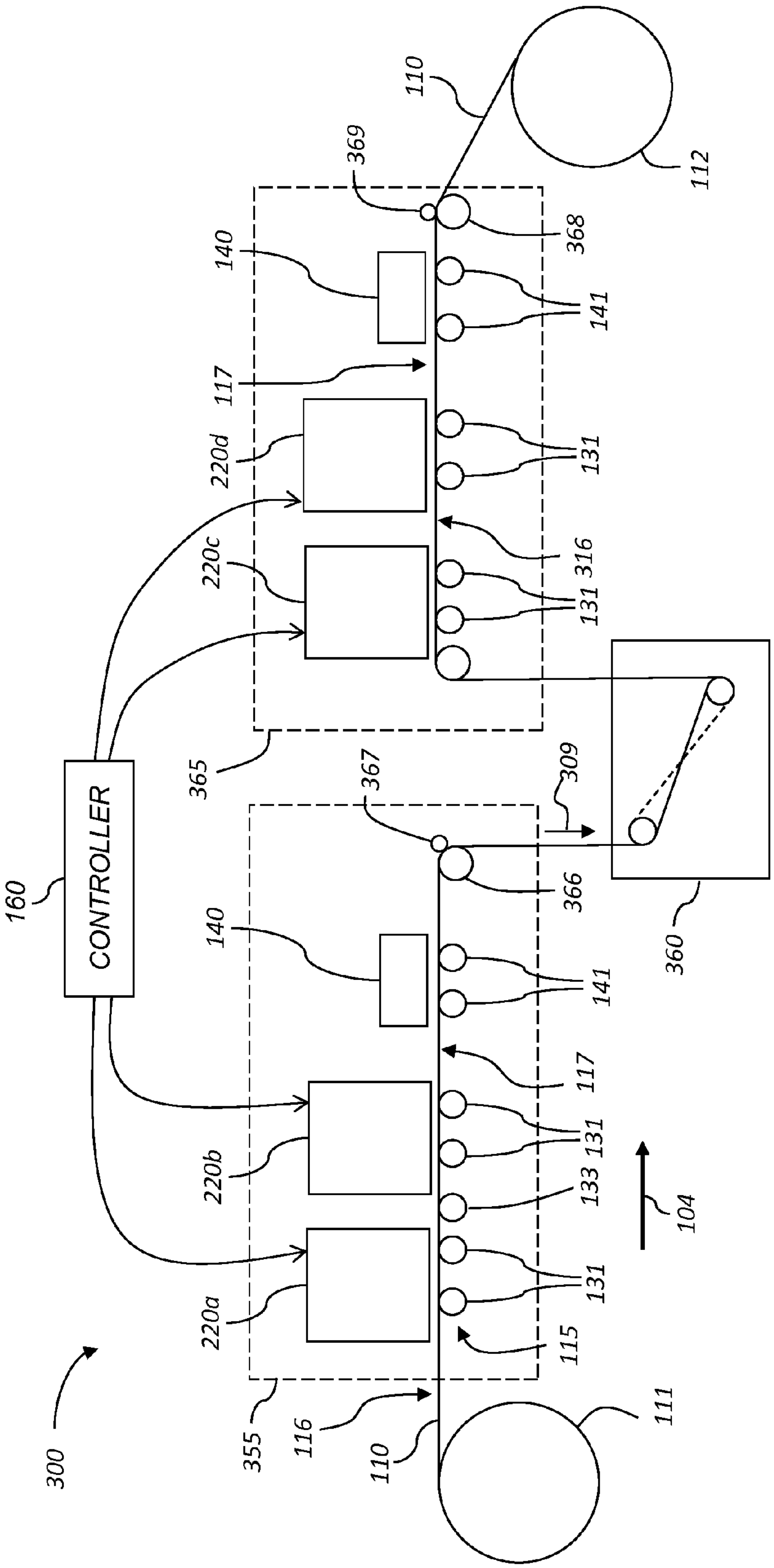
112
115
151
152
104
L_{ab}
L_{cd}
C_R

FIG. 7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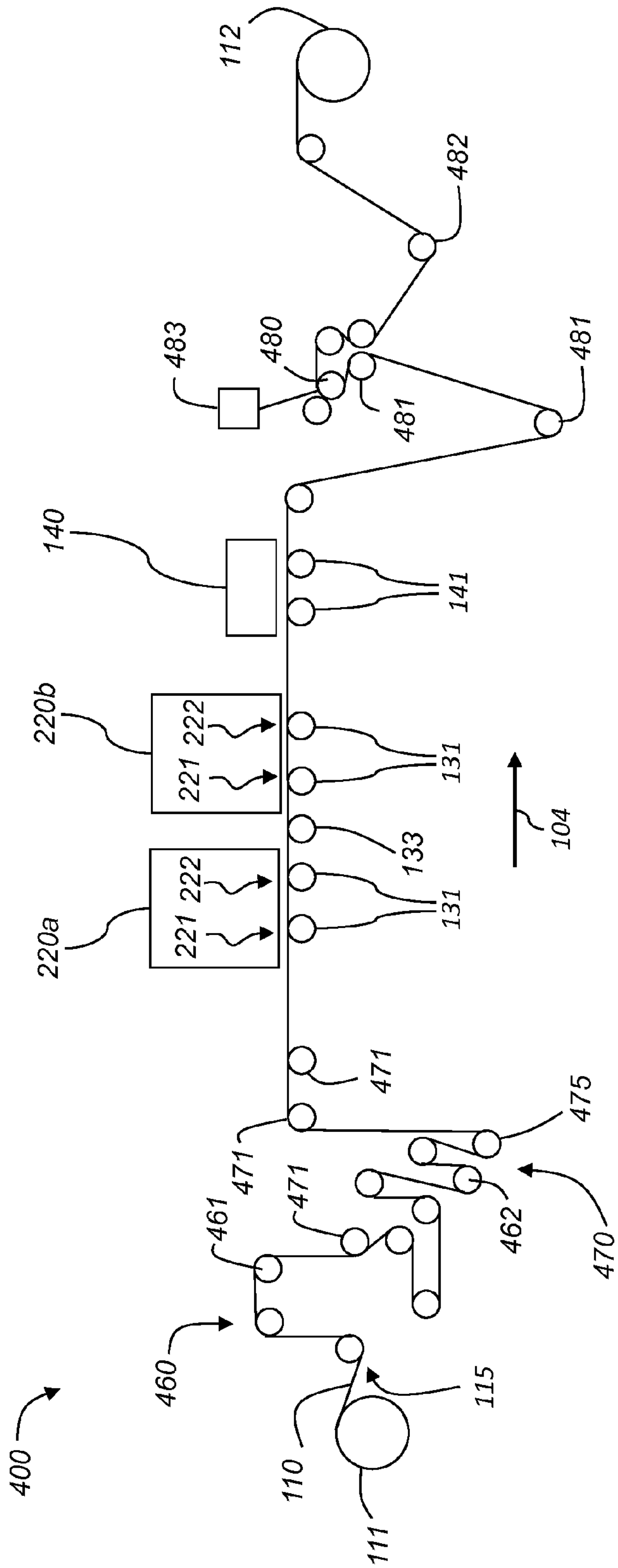
300
110
111
112
116
115
117
140
141
131
133
104
220a
220b
220c
220d
316
309
355
365
360
366
367
368
369

FIG. 8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483
480
481
481
140
141
220b
222
221
131
133
104
220a
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221
131
471
475
471
471
461
462
470
460
115
110
400
111

FIG. 9

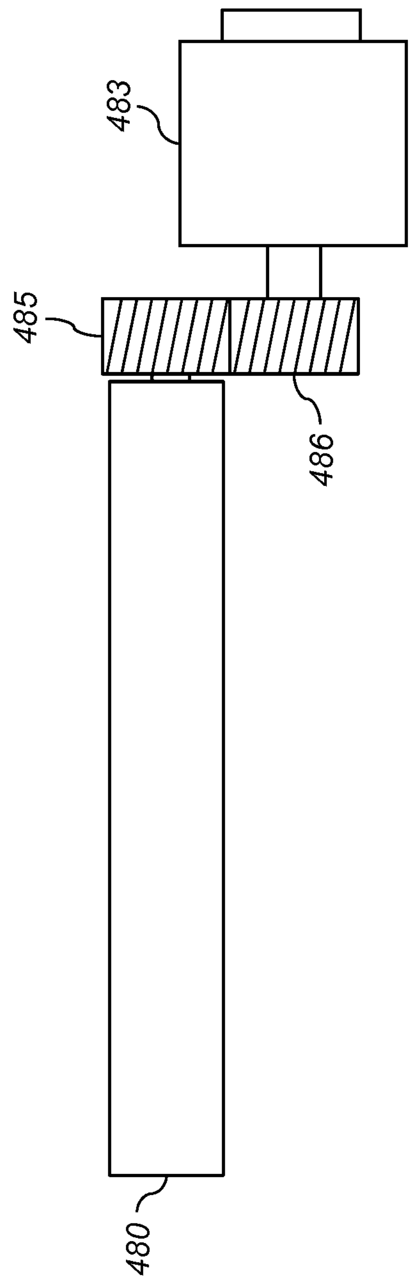

FIG. 10

DRIVE GEARS PROVIDING IMPROVED REGISTRATION IN DIGITAL PRINTING SYSTEMS

CROSS REFERENCE TO RELATED APPLICATIONS

Reference is made to commonly assigned, co-pending U.S. patent application Ser. No. 14/280,707, entitled "Precision registration in printing cylinder systems" by K. Peter et al; to commonly assigned, co-pending U.S. patent application Ser. No. 14/280,714, entitled "Drive gears providing improved registration in printing cylinder systems" by K. Peter et al; and to commonly-assigned, co-pending U.S. patent application Ser. No. 14/280,718, entitled "Precision Registration in a Digital Printing System" by Peter et al., each of which is incorporated herein by reference.

FIELD OF THE INVENTION

This invention relates generally to the field of digital printing systems, and more particularly to a web transport design for improved registration of printed patterns from different printing stations in a roll-to-roll printing system.

BACKGROUND OF THE INVENTION

In a digitally controlled printing system, for example an inkjet printing system, a print media is directed through a series of components. The print media can be a cut sheet or a continuous web. A web or cut sheet transport system physically moves the print media through the printing system. As the print media moves through the printing system, marks are controllably made on the print media by one or more printheads, which are typically not in contact with the print media, to form the desired image or pattern.

For printing a color image, the printing system can have a plurality of printing stations, each having a printhead for printing one of the color channels (e.g., cyan, magenta, yellow and black) that make up the color image. If suitable color-to-color registration is not maintained in the printing system, print defects such as color halos at the edges of multicolor features can be seen.

Similarly, functional printing of devices can be done in multiple successive steps using a plurality of printing stations. If suitable registration is not maintained between printing stations, the performance of the printed device can be degraded. In fact, the desired registration tolerances for functional printing can be tighter than what is required for color image printing.

One approach for achieving registration of patterns printed by different printheads on a web of media is to use in-situ measurement techniques on the printed web such that the registration can be monitored and controlled to be within a required tolerance. Registration marks can be printed on the web of media at the same time as each color layer of the image is printed. The registration marks can be monitored by a control system and appropriate adjustments can be made to the printing process. For example, registering a pattern along the web motion direction (also called the in-track direction) that is being printed by a second digital printhead to a pattern that was printed previously by first digital printhead can be done by controlling the timing of the marking process of the second digital printhead. For example, for inkjet printheads the timing of the jetting of the ink drops by the second printhead can be advanced or delayed as needed.

Although methods exist for registering portions of the print that are successively printed by different printheads, what is needed for precision printing is to design the web transport for a roll-to-roll digital printing system in such a way that the size of registration errors introduced in the printing system is reduced.

SUMMARY OF THE INVENTION

The present invention represents a printing system for printing on a web of media traveling along a web transport path, comprising:

a plurality of printheads for printing on the web of media, each of the printheads being configured to print at one or more corresponding print locations along the web transport path;

a plurality of web transport rollers to guide the web of media along the web transport path;

one or more drive rollers for causing the web of media to move along the web transport path, the drive rollers having an affixed driven gear driven by a motor using a gear train including one or more drive gears which transfer torque from the motor to the driven gear;

wherein the driven gear and the drive gears associated with the drive rollers are constrained to rotate substantially an integer number of times as the web of media is advanced along the web transport path between two successive print locations.

This invention has the advantage that disturbances in the motion of the web of media caused by any run-out or other imperfections in the web-transport rollers are made more consistent by keeping the rollers all in phase with each other.

It has the additional advantage that registration errors between image data printed by the different print stations are reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a view of a face of a digital printhead having a single print line;

FIG. **2** is a simplified side view of a digital printing system for printing on a web of media using single-print-line printheads;

FIG. **3** is a view of a face of a digital printhead having two staggered print lines;

FIG. **4** is a simplified side view of a digital printing system for printing on a web of media using two-print-line printheads;

FIG. **5** is a simplified side view of a digital printing system for printing on a web of media using two-print-line printheads according to an alternate embodiment;

FIG. **6** is a view of a face of two digital printheads, each having two staggered print lines;

FIG. **7** is a simplified side view of a digital printing system for printing on a web of media using two-print-line printheads shown in FIG. **6**;

FIG. **8** is a simplified side view of a digital printing system for printing on both sides of a web of media;

FIG. **9** shows a schematic view of a portion of a digital printing system including additional web transport rollers near the supply roller and the take-up roller; and

FIG. **10** shows components for driving the main drive roller of FIG. **9** according to an exemplary embodiment.

It is to be understood that the attached drawings are for purposes of illustrating the concepts of the invention and may not be to scale.

DETAILED DESCRIPTION OF THE INVENTION

The present description will be directed in particular to elements forming part of, or cooperating more directly with, an apparatus in accordance with the present invention. It is to be understood that elements not specifically shown, labeled, or described can take various forms well known to those skilled in the art. In the following description and drawings, similar or identical reference numerals have been used, where possible, to designate identical elements. It is to be understood that elements and components can be referred to in singular or plural form, as appropriate, without limiting the scope of the invention.

The invention is inclusive of combinations of the embodiments described herein. References to "a particular embodiment" and the like refer to features that are present in at least one embodiment of the invention. Separate references to "an embodiment" or "particular embodiments" or the like do not necessarily refer to the same embodiment or embodiments; however, such embodiments are not mutually exclusive, unless so indicated or as are readily apparent to one of skill in the art. It should be noted that, unless otherwise explicitly noted or required by context, the word "or" is used in this disclosure in a non-exclusive sense.

The example embodiments of the present invention are illustrated schematically and not to scale for the sake of clarity. One of ordinary skill in the art will be able to readily determine the specific size and interconnections of the elements of the example embodiments of the present invention.

As described herein, the exemplary embodiments of the present invention provide a printhead or printhead components typically used in digital printing systems such as inkjet printing systems. However, many other applications are emerging which use digital printheads to make marks of various types on print media (sometimes called receiver media). For example, inkjet printheads can be used to emit liquids that need to be finely metered and deposited with high spatial precision. Such liquids include inks, both water-based and solvent-based, that include one or more dyes or pigments. These liquids also include various substrate coatings and treatments, various medicinal materials, and functional materials useful for forming, for example, various circuitry components or structural components. As such, as described herein, the terms "liquid" and "ink" refer to any material that is ejected by inkjet printheads or inkjet printhead components described below.

Inkjet printing is commonly used for printing on paper, however, there are numerous other materials in which inkjet is appropriate. For example, the print media can be vinyl sheets, plastic sheets, textiles, paperboard, or corrugated cardboard. Additionally, although the term inkjet is often used to describe the printing process, the term jetting is also appropriate wherever ink or other liquids is applied in a consistent, metered fashion, particularly if the desired result is a thin layer or coating.

Inkjet printing is a non-contact application of a liquid such as an ink to a print media. Typically, one of two types of ink jetting mechanisms are used and are categorized by technology as either drop on demand ink jet (DOD) or continuous ink jet (CIJ).

The first technology, "drop-on-demand" (DOD) ink jet printing, provides ink drops that impact upon a recording surface using a pressurization actuator, for example, a thermal, piezoelectric, or electrostatic actuator. One commonly practiced drop-on-demand inkjet type uses thermal energy to eject ink drops from a nozzle. A heater, located at or near the nozzle, heats the ink sufficiently to form a vapor bubble that creates enough internal pressure to eject an ink drop. This form of inkjet is commonly termed "thermal ink jet." A second commonly practiced drop-on-demand inkjet type uses piezoelectric actuators to change the volume of an ink chamber to eject an ink drop.

The second technology, commonly referred to as "continuous" ink jet (CIJ) printing, uses a pressurized ink source to produce a continuous stream of ink by forcing ink, under pressure, through a nozzle. The stream of ink is perturbed using a drop forming mechanism such that the stream of ink breaks up into drops of ink in a predictable manner. One continuous inkjet printing type uses thermal stimulation of the stream of ink with a heater to form drops that eventually become print drops and non-print drops. Printing occurs by selectively deflecting either the print drops or the non-print drops and catching the non-print drops. Various approaches for selectively deflecting drops have been developed including electrostatic deflection, air deflection, and thermal deflection.

More generally, digital printing systems can include printheads having arrays of marking elements that are controlled to make marks on a print media as the printheads and print media are moved relative to one another in order to form a desired pattern. FIG. **1** is a view of a face of a printhead **120** having a support structure **130** onto which a plurality of printhead modules **123** are mounted. Each printhead module **123** includes a marking element array **124**. In the example shown in FIG. **1** there are six printhead modules **123** mounted end to end on a surface **139** of support structure **130** so that the marking element arrays **124** are disposed substantially along a single print line **121** that is parallel to the marking element array direction **106** (also called the cross-track direction). In the particular case where printhead **120** is an inkjet printhead, marking elements in the marking element array **124** are inkjet nozzles. With reference to FIG. **1**, the web of media (not shown) would be moved past printhead **120** along media advance direction **104** (also called the in-track direction).

The invention described herein is applicable to both drop on demand and continuous inkjet printing technologies, as well as other digital printing technologies employing a printhead including an array of marking elements. As such, the term printhead, as used herein, is intended to be generic and not specific to a particular technology.

Referring to FIG. **2**, there is shown a simplified side view of a portion of an inkjet printing system **100** for printing on a first side of a continuous web of media **110**. The inkjet printing system **100** includes a printing module **150** which includes printheads **120***a*, **120***b*, **120***c*, **120***d*, dryers **140**, and a quality control sensor **145**. In this example, the first (leftmost) printhead **120***a* jets cyan ink, the second printhead **120***b* jets magenta ink, the third printhead **120***c* jets yellow ink, and the fourth (rightmost) printhead **120***d* jets black ink. A controller **160** controls the inkjet printing system **100**, and performs various control functions including controlling the printheads **120***a*, **120***b*, **120***c*, **120***d* according to image data to produce a printed image.

Web transport rollers guide the web of media **110** from upstream to downstream along a web transport path **115** through the printing module **150**. (The terms "upstream" and "downstream" are terms of art referring to relative positions along the web transport path **115**; points on the web of media **110** move from upstream to downstream.) In this example, below each printhead **120***a*, **120***b*, **120***c*, **120***d* is a corresponding print line roller **131** that guides the web of media **110** in the media advance direction **104** past a corresponding print line **121***a*, **121***b*, **121***c*, **121***d* as the web of media **110** is advanced along the web transport path **115** through printing module **150**. Below each dryer **140** is at least one dryer roller **141** for controlling the position of the web of media **110** near the dryers **140**. Various other support rollers **133** also support and guide the web of media **110** as it moves along the web transport path **115** through printing module **150**.

The web of media **110** originates from a supply roll **111** of unprinted print media and ends up on a take-up roll **112** of printed print media. Other details of printing system are not shown in FIG. **2** for simplicity. To the left of printing module **150**, a first zone **151**, illustrated as a break in the web of media **110**, can include a slack loop, a web tensioning system, an edge guide and other elements that are not shown in FIG. **2**. To the right of printing module **150**, a second zone **152**, illustrated as a break in the web of media **110**, can include other components such as a turnover mechanism (e.g., see FIG. **8**) and a second printing module (e.g., see FIG. **8**) similar to printing module **150** for printing on a second side of web of media **110**.

Embodiments of the invention provide design criteria for a printing system **100** that prints on a continuous web of media **110** traveling along a web transport path **115**, where the printing system **100** has a plurality of printheads **120***a*, **120***b*, **120***c*, **120***d* for printing on the web of media **110**, each of the printheads **120***a*, **120***b*, **120***c*, **120***d* being configured to print at one or more corresponding print locations (e.g., at print lines **121***a*, **121***b*, **121***c*, **121***d*) along the web transport path **115**. The design criteria are intended to reduce disturbances in the motion of the web of media **110** as it is conveyed through the printing system **100**. By reducing such disturbances there is greater reproducibility and registration precision in the composite printed patterns that are formed by the plurality of printheads at the various print locations.

In particular it is observed that the web-transport rollers, including print line rollers **131**, dryer rollers **141** and support rollers **133** tend not to be perfectly uniform. A roller can be out of round or eccentrically mounted for example. Such non-uniformities in rollers supporting the web of media **110** can result in non-uniformity in the motion of the web of media **110**. This can adversely affect registration between successive printed patterns along media advance direction **104**. In order to reduce the overall non-uniformity in the motion of the web of media **110**, it is beneficial for the individual non-uniformities of the various web-transport rollers to remain in phase from one print location to the next print location. It is therefore advantageous for each web transport roller in a printing module **150** to complete an integer number of revolutions as the web of media **110** is advanced from one print location (e.g. print line **121***a*) to the next downstream print location (e.g. print line **121***b*). This design criterion can equivalently be stated as each of the plurality of web transport rollers (including print line rollers **131**, dryer rollers **141** and support rollers **133**) has a roller circumference C_R that is substantially equal to an integer fraction of a span L of the web of media **110** between two successive print locations. That is, the roller circumference C_R of each web-transport roller satisfies the design criterion that:

$$C_R = L/N \tag{1}$$

where N is a positive integer. By substantially equal it is meant that the roller circumference C_R of each of the web transport rollers is equal to an integer fraction of the span of the web of media **110** between successive print locations to within 1.0%, and more preferably to within 0.1%.

It is not required that the web transport rollers all have the same roller circumference as each other, only that each web transport roller has a circumference that is an integer fraction of the span L of the web of media **110** between successive print locations. However, the case where all web transport rollers have the same circumference can be advantageous from the standpoint of commonality of parts.

Where the web of media **110** follows a substantially straight path (as is the case between successive print lines **121***a* and **121***b* in the example shown in FIG. **2**), the span (e.g., L_{ab}) of the web of media **110** is simply the distance between print lines **121***a* and **121***b*. Where the web of media **110** is not straight (as between print lines **121***b* and **121***c* in the example shown in FIG. **2**), the span (e.g., L_{bc}) of the web of media **110** is the total length of the web between the print locations if the curved web were pulled straight, so that the span is longer than the straight line distance between the two successive print locations.

In the example shown in FIG. **2**, not all of the web spans between successive print locations are the same. In particular, because there is no dryer **140** between printheads **120***a* and **120***b*, the web span L_{ab} between the first and second print locations corresponding to print lines **121***a* and **121***b* is shorter than the web span L_{bc} between second and third print locations corresponding to print lines **121***b* and **121***c*. The web span L_{ab} between first and second print locations corresponding to print lines **121***a* and **121***b* is also shorter than the web span L_{cd} between third and fourth print locations corresponding to print lines **121***c* and **121***d*. In order to keep roller non-uniformities in phase from one print location to the next, it is beneficial for each web span L_{ab}, L_{bc}, L_{cd} to be substantially equal to integer multiples of the roller circumferences C_R of each of the various web transport rollers in the printing module **150**. In this case, the roller circumference C_R of each web-transport roller should satisfy the design criterion that:

$$C_R = L_{ab}/N_1 = L_{bc}/N_2 = L_{cd}/N_3 \tag{2}$$

where N_1, N_2 and N_3 are positive integers. Positioning the various components of the printing system to satisfy this design criterion will have the effect that each of the web-transport rollers will be in the same angular orientation (i.e., have the same phase) whenever a particular location on the web of media **110** is passing by each of the print lines **121***a*, **121***b*, **121***c*, **121***d*. As a result, any non-uniformities in the motion of the web of media **110** caused by irregularities in the web-transport rollers will be consistent at each print location, thereby reducing relative registration errors between the image content printed by the different printheads **120***a*, **120***b*, **120***c*, **120***d* (e.g., color-to-color registration errors). Furthermore, the registration errors for the image content printed by a particular **120***a*, **120***b*, **120***c*, **120***d* will be much more consistent and predictable from one frame to another since the rollers will all be in consistent angular orientations for a given location within the frame. As a result, the registration errors can be characterized as a function of position within the image frame (for example by using the quality control sensor **145** to sense the position of registration marks printed in the margin of the printed image), and can be compensated for by providing a correction function which specifies compensating shifts to be applied during the process of printing the image data. For example, if a particular image line at a particular location within the image frame is found to be consistently shifted by a certain displacement from its nominal position, then the controller **160** can control the timing of when the printheads **120***a*, **120***b*, **120***c*, **120***d* print the image data for that print line accordingly (e.g., the timing can be advanced or delayed).

Although the printhead shown in FIG. **1** and used in the inkjet printing system **100** of FIG. **2** has a single print line **121** of marking element arrays **124**, other configurations of printheads can have marking element arrays that are disposed along a plurality of print lines. FIG. **3** is a view of a face of a printhead **220** having a support structure **230** with a surface **239** on which are mounted a plurality of printhead modules **223** positioned in two rows in a staggered arrangement.

In the exemplary embodiment of FIG. **3**, the printhead **220** includes three inkjet nozzle arrays **225***a*, **225***b* and **225***c* arranged along a first print line **221**, each inkjet nozzle array **225***a*, **225***b*, **225***c* including a corresponding group of nozzles **224** that extends along the first print line **221** in a marking element array direction **106**. Inkjet nozzle array **225***a* is separated from inkjet nozzle array **225***b* along first print line **221** by an intervening non-printing region R. Similarly, printhead **220** also includes three inkjet nozzle arrays **226***a*, **226***b* and **226***c* arranged along a second print line **222**, each inkjet nozzle array **226***a*, **226***b*, **226***c* including a corresponding group of nozzles **224** that extend along second print line **222** in the marking element array direction **106**. The inkjet nozzle array **226***a*, **226***b*, **226***c* disposed along the second print line **222** are adapted to eject drops of ink (not shown) onto portions of the receiver medium that are complementary to portions that are printed by the inkjet nozzle arrays **225***a*, **225***b*, **225***c* disposed along the first print line **221**. Adjacent inkjet nozzle arrays **226***a*, **226***b*, **226***c* are separated from each other along second print line **222** by intervening non-printing regions R. An inkjet printhead **220** having such a staggered formation including inkjet nozzle arrays **225***a*, **225***b*, **225***c*, **226***a*, **226***b*, **226***c* arranged along first and second print lines in an alternating pattern is sometimes called a "staggered inkjet printhead." The first and second print lines **221** and **222** are parallel and are spaced apart along media advance direction **104** by a spacing distance W, which in some embodiments is on the order of six inches. If a web of media **110** (FIG. **4**) is advanced along media advance direction **104** at a speed S, then a timing delay of $\Delta t=W/S$ of ejecting drops of ink from nozzles **224** in second print line **222** is used relative to ejecting drops of ink from nozzles **224** in first print line **221**. In that way, if the image to be printed includes a straight line across the web of media **110**, portions of the straight line printed by nozzles **224** from first print line **221** will line up with portions of the straight line printed by nozzles **224** from second print line **222**. Inkjet nozzle arrays **225***a*, **225***b*, **225***c* along first print line **221** are offset from inkjet nozzle arrays **226***a*, **226***b*, **226***c* such that the non-printing regions R along first print line **221** are aligned with the inkjet nozzle arrays **226***a*, **226***b*, **226***c* along second print line **222**, and vice versa. The ends of the inkjet nozzle arrays **225***a*, **225***b*, **225***c* of the first print line **221** generally overlap with the ends of the inkjet nozzle arrays **226***a*, **226***b*, **226***c* of the second print line **222** to produce overlap regions V. The overlap regions V enable the printed image from overlapped inkjet nozzle arrays **225***a*, **225***b*, **225***c*, **226***a*, **226***b*, **226***c* to be stitched together without a visible seam through the use of appropriate stitching algorithms that are known in the art.

Referring to FIG. **4**, there is shown a simplified side view of a portion of an inkjet printing system **200** for printing on a first side of a continuous web of media **110** of print media using staggered inkjet printheads **220***a*, **220***b*, **220***c*, **220***d* of the type shown in FIG. **3**. The inkjet printing system **200** includes a printing module **250** which includes printheads **220***a*, **220***b*, **220***c*, **220***d*, dryers **140**, and a quality control sensor **145**. In this example, the first (leftmost) printhead **220***a* jets cyan ink, the second printhead **220***b* jets magenta ink, the third printhead **220***c* jets yellow ink, and the fourth (rightmost) printhead **220***d* jets black ink. Below each printhead **220***a*, **220***b*, **220***c*, **220***d* are print line rollers **131** that guide the web of media **110** past the first print line **221** and the second print line **222** of each printhead **220***a*, **220***b*, **220***c*, **220***d* as the web of media **110** is advanced through the printing module **250** along the web transport path **115**. Below each dryer **140** is at least one dryer roller **141** for controlling the position of the web of media **110** near the dryers **140**. Various other support rollers **133** also support and guide the web of media **110** as it moves along the web transport path **115** through printing module **250**. The web of media **110** originates on a supply roll **111** of unprinted print media and ends up on a take-up roll **112** of printed print media. Other details of printing system are not shown in FIG. **4** for simplicity. To the left of printing module **250**, a first zone **151** illustrated as a break in the web of media **110** can include a slack loop, a web tensioning system, an edge guide and other elements that are not shown. To the right of printing module **250**, a second zone **152** illustrated as a break in the web of media **110** can include elements such as a turnover mechanism (not shown) and a second printing module (not shown) similar to printing module **250** for printing on a second side of the web of media **110**.

Registration considerations for inkjet printing system **200** of FIG. **4** are similar to the registration considerations for the inkjet printing system **100** of FIG. **2** that were described above. However, printheads **220***a*, **220***b*, **220***c*, **220***d* of the type shown in FIGS. **3** and **4** have a plurality of print lines **221**, **222** for each printhead **220***a*, **220***b*, **220***c*, **220***d*. It is important to maintain good registration of dots formed on the web of media **110** by print locations corresponding to first and second print lines **221** and **222** of each printhead **220** in addition to maintaining good registration of dots formed by the different printheads **220***a*, **220***b*, **220***c*, **220***d*. It is therefore advantageous for each web transport roller in printing module **250** to complete an integer number of revolutions while advancing the web of media **110** from one print location (e.g., first print line **221** of printhead **220***a*) to the next print location (e.g., second print line **222** of the same printhead **220***a*). This design rule can equivalently be stated as each of the plurality of web transport rollers (including print line rollers **131**, dryer rollers **141** and support rollers **133**) has a roller circumference C_R that is substantially equal to an integer fraction of a span of the web of media **110** between two successive print locations that correspond to first print line **221** and second print line **222** of each printhead **220***a*, **220***b*, **220***c*, **220***d*. Since the distance between first and second print lines **221** and **222** is W (FIG. **3**), if the web of media **110** is straight between the first print line **221** and the second print line **222**, as in FIG. **4**, then the design criterion is that:

$$C_R=W/M \tag{3}$$

where M is a positive integer. In a preferred embodiment, both this design criterion and the design criterion discussed earlier with respect to Eqs. (1)-(2) are satisfied simultaneously. However, a partial benefit can be obtained if even one of these design criteria is satisfied.

Other design considerations for web transport rollers include strength and stability, which are related to the size and weight of media to be used in the printing system, as well as the intended web tension and the wrap angle of the media around the web transport rollers. If the diameter of a web transport roller is too small, it will have insufficient strength to support the web of media **110** without flexing and causing conveyance non-uniformity. As indicated above with reference to FIG. **3**, in some embodiments the distance between first and second print lines **221** and **222** on printhead **220** can be on the order of six inches. Since the circumference of a cylinder is $C_R=\pi D$, where D is the diameter of the cylinder, if the web of media **110** is straight between first and second print lines **221** and **222** as in FIG. **4**, then the design rule that each web transport roller circumference C_R is substantially equal to W/M can require that the diameter of the various web transport rollers be less than two inches in such embodiments. A two inch diameter can be too small for sufficient strength and stability in a web transport roller in a printing system. In such cases, the web transport path **115** can be modified as shown in FIG. **5** by inserting a span extension roller **135** (or some other type of span extension member such as a fixed media guide or an air shoe) between the pair of print line rollers **131** corresponding to each printhead **220***a*, **220***b*, **220***c*, **220***d*. In this way, the web span between print locations corresponding to first and second print lines **221** and **222** for each printhead **220***a*, **220***b*, **220***c*, **220***d* can be increased to provide an extended spacing distance W_e so that the diameters of the web transport rollers (including print line rollers **131**, span extension rollers **135**, dryer rollers **141** and support rollers **133**) can be larger to provide greater stability while still satisfying the design rule that each of the plurality of web transport rollers has a roller circumference that is substantially equal to an integer fraction of the span of the web of media **110** between two successive print locations that correspond to first and second print lines **221** and **222** of a particular printhead **220***a*, as well as between the print locations associated with the different printheads **220***a*, **220***b*, **220***c*, **220***d*.

Since the span extension roller **135** in the configuration of FIG. **5** contacts the imaging side of the web of media **110** just after the ink is applied at print line **221**, the use of a conventional roller may not be desirable in some cases, depending on the ink and media characteristics, if the ink will not be sufficiently dried and adhered to the web of media **110** prior to coming into contact with the span extension roller **135**. To mitigate any problems that could occur due to ink smearing, a contoured roller (or a contoured fixed media guide) as described in commonly-assigned, co-pending U.S. patent application Ser. No. 13/923,403 to Kasiske et al., entitled "Inkjet printing system with contoured media guide," which is incorporated herein by reference, can be used for the span extension roller **135**. In this case, the span extension roller **135** is provided with a contoured surface which has recessed areas that are aligned with the inkjet nozzle arrays **225***a*, **225***b*, **225***c* (FIG. **3**) in the first print line **221**, so that the span extension roller **135** only contacts the web of media **110** in regions that were not printed at the first print line **221**.

Alternately, the span extension member can be an air shoe where the web of media **110** rides around the air shoe on a cushion of air so that the printed surface of the web of media **110** does not contact the surface of the air shoe. Air shoes are well-known in the media-guiding art and generally include a fixed media guide surface with holes or grooves through which a stream of air is blown to lift the media away from the media guide surface. In some embodiments, the air shoe can be of the type described in commonly-assigned, co-pending U.S. patent application Ser. No. 14/190,146 to Cornell et al., entitled "Air shoe with roller providing lateral constraint," which is incorporated herein by reference.

FIG. **6** illustrates an alternate configuration of printhead modules **223** within a pair of printheads **240***a* and **240***b* which can be used to satisfy the design criteria set forth in this disclosure, without the use of a span extension member. In this embodiment, the staggered printhead modules **223** in printhead **240***b* are arranged in a mirror image configuration relative to the printhead **240***a*. In this case, the printheads **240***a*, **240***b* are operated such that a first color is jetted using print line **221** of print **240***a*, and the same first color is jetted in using print line **221** of printhead **240***b*. Since the printhead modules **223** in these print lines are provided in a staggered arrangement, they will fully cover the entire media width. Similarly, a second color is jetted in using print line **222** in the print head **240***a* and the print line **222** in the print head **240***b*. According to this arrangement, the distance between the print locations used to print the first color will be L_{ab} and the distance between the print locations used to print the second color will also be L_{ab}.

FIG. **7** illustrates an inkjet printing system **205** using the printheads **240***a*, **240***b* of FIG. **6**. The third and fourth printheads **240***c* and **240***d* used for printing third and fourth colors are also provided using an analogous arrangement. According to this configuration, if the web-transport rollers (e.g., print line rollers **121**, support rollers **133** and dryer rollers **141**) are selected to satisfy the design criterion that their circumferences C_R be integer fractions of L_{ab} and L_{cd} (i.e., they satisfy the design criterion given in Eq. (2)), then this will provide a consistent phase relationship of the angular orientations within a particular color channel. As a result, any irregularities in the motion of the web of media **110** should be consistent between the locations that a given color is printed (e.g., between print line **221** of print **240***a* and print line **221** of printhead **240***b* and between print line **222** of print **240***a* and print line **222** of printhead **240***b*).

For the embodiment illustrated in FIG. **6-7**, the design criterion given in Eq. (3) that the roller circumference be an integer fraction of the print line spacing distance W can optionally be relaxed. This enables the use of larger diameter rollers without using span extension rollers **135** (FIG. **5**). For cases where Eq. (3) is not satisfied, the phase relationships of the angular orientations of the rollers will be different for the first and second colors. However, since the phase relationship will be consistent and predicable within a particular color, the resulting position errors can be characterized and corrected on a color-by-color basis to correct any color-to-color registration errors that might result.

Referring to FIG. **8**, there is shown a simplified side view of a portion of an inkjet printing system **300** for printing on both a first side **116** and a second side **117** of a continuous web of media **110** that is advanced along media advance direction **104** from supply roll **111** to take-up roll **112**. Inkjet printing system **300** includes a first printing module **355**, for printing on a first side **116** of the web of media **110**, having two printheads **220***a*, **220***b* and a dryer **140**; a turnover mechanism **360**; and a second printing module **365**, for printing on the second side **117** of the web of media **110**, having two printheads **220***c*, **220***d* and a dryer **140**. Web transport rollers guide the web of media **110** from upstream to downstream along web transport path **115** through the first printing module **355** and the second printing module **365**. The web transport rollers include print line rollers **131** aligned with the print lines (not shown in FIG. **8**) of the printheads **220***a*, **220***b*, **220***c*, **220***d*. These print line rollers **131** maintain the web of media **110** at a fixed spacing from the printheads to ensure a consistent time of flight for the print drops emitted by the printheads **220***a*, **220***b*, **220***c*, **220***d*. The web transport rollers also include dryer rollers **141** and other support rollers **133**. The web transport rollers also include a drive roller **366** which applies tension to the web of media **110** and directs it along exit direction **309** of first printing module **355** toward the turnover mechanism **360**. A nip roller **367** holds the web of media **110** in contact with the drive roller **366**. The web transport rollers also include a second drive roller **368** near the exit of second printing module **365** which applies tension to the web of media **110** and directs it toward take-up roll **112**. A nip roller **369** holds the web of media **110** in contact with the drive roller **368**. Motors (not shown in FIG. **8**) rotate drive rollers **366**, **368**, thereby providing a force to move the web of media **110** along the web transport path **115**. The other web transport rollers, including print line rollers **131**, span extension rollers **135** (FIG. **5**), dryer rollers **141**, and other support rollers **133** can be freely rotating idler rollers. As in the previously discussed embodiments, each of the plurality of web transport rollers, including drive rollers **366**, **368** as well as the idler rollers, preferably has a roller circumference C_R that is substantially equal to an integer fraction of a span of web of media **110** between two successive print locations.

Transport roller size has previously been considered in different ways for web transport in a printing system. For example, Kodak's NexPress line of color electrophotographic printers has a seamed transport web for advancing cut sheets of paper past a series of electrophotographic print modules. All rollers used in this assembly, including the main drive roller, tension roller, steering roller, detack roller, touch down roller, guide rollers, and paper transfer rollers are designed in a way that their circumference matches an integer fraction of the print module-to-module spacing. So, for example, the main drive roller rotates exactly 3 times while the transport web moves from one print module to the next, while the receiver is firmly attached to the transport web. In consequence, all periodic variations due to roller run-out or unbalance that might cause an in-track timing problem stay in phase between the print modules and do not show up as a print registration problem. Line spacing might vary from the ideal pitch (e.g., 600 lines per inch), but registration is not affected because the variation occurs in the same way in all print modules. Although the motivation of precision registration is similar in the present invention, the design criterion is different for printing systems using a continuous web of media **110** rather than cut sheets as in the NexPress printers. Rather than the transfer rollers having a circumference that is equal to an integer fraction of the print module-to-module spacing as in the cut sheet system, the web transport rollers have a circumference that is equal to an integer fraction of a span of the web of media **110** between two successive print locations. The design criterion for web transport systems allows for web transport paths that are not straight lines between successive print locations.

Other differences in design criteria in embodiments of the invention result from a roll-to-roll printing system architecture. With reference to FIG. **2**, the supply roll **111** continues to decrease in diameter, while the take-up roll **112** continues to increase in diameter as the web of media **110** is advanced through printing system **100**. FIG. **9** shows a schematic side view of a portion of an inkjet printing system **400** where only two printheads **220***a*, **220***b* are visible, in order to illustrate additional rollers between supply roll **111** and the first print location (first print line **221** of first printhead **220***a*), as well as between the last print location (second print line **222** of second printhead **220***b*) and take-up roll **112**.

Inkjet printing system **400** includes a media guiding subsystem **460** downstream of supply roll **111**. The media guiding subsystem **460** can move side-to-side and helps to guide the web of media **110** to start down the web transport path **115** as it unwinds from supply roll **111**, and generally includes one or more web-transport rollers **461** and other components such as edge guides and control systems. An out-of-round supply roll **111** will cause disturbances on the motion of the web of media **110** at increasing frequency as the web is unwound. A front-end motion isolation mechanism, such as an S-wrap tensioning subsystem **470** is commonly provided to buffer such disturbances and allow a steady motion of the continuous web of media **110** at controlled tension throughout the inkjet printing system **400**. The S-wrap tensioning subsystem **470** generally includes two or more web-transport rollers **462** which define an S-shaped media path. In alternate embodiments, other types of motion isolation mechanism can be used such as slack loops or festoons. Additional web transport rollers **471** are located along the web transport path **115** between the supply roll **111** and the first print location associated with the first print line **221** of first printhead **220***a*.

On the output side of inkjet printing system **400**, a main drive roller **480** driven by a motor **483** is used to pull the web of media **110** at a predetermined tension measured with a load cell roller **475**. The main drive roller **480** also serves the function of a back-end motion isolation mechanism to isolates the printheads **220***a*, **220***b* from the take-up roll **112**. In alternate embodiments, other types of motion isolation mechanism can be used such as slack loops or festoons. Additional web transport rollers **481** are also located along the web transport path **115** between the last print location (corresponding to the second print line **222** of the second printhead **220***b*) and the take-up roll **112**.

The design criterion described above constraining the circumference of each of the web transport rollers, is preferably also applied to some or all of the web transport rollers **471**, **481**, **482**, the load cell roller **475**, the main drive roller **480**, and any rollers associated with the media-guiding subsystem **460** and the S-wrap subsystem **470**. In some embodiments one or more of the constrained web-transport rollers can include encoders or tachometers that are used to characterize web motion. There is particular benefit to constraining the web-transport rollers **471** between the S-wrap tensioning subsystem **470** and the first printhead **220***a*, as well as the web-transport rollers **462**, **475** in the S-wrap tensioning subsystem **470**, to be selected according to the aforementioned design criteria. Since the S-wrap tensioning subsystem **470** serves to effectively isolate the supply roll **111** and media guiding subsystem **460** from the printheads **220***a*, **220***b*, the benefit of constraining any web-transport rollers **461** upstream of the S-wrap tensioning subsystem **470** to conform to the design criteria is reduced. Likewise, it is preferable that the main drive roller **480**, as well as any web-transport rollers **481** between the last printhead **220***b* and the main drive roller **480**, be constrained to satisfy the aforementioned design criteria. Since the main drive roller **480** effectively isolates the printheads **220***a*, **220***b* from the take-up roll **112**, the benefit of constraining the web-transport rollers **482** downstream of the main drive roller **480** to conform to the design rule is reduced.

In some embodiments, the main drive roller **480** is driven by the motor **483** using a direct servo drive. In other embodiments, as illustrated in FIG. **10**, a driven gear **485** can be affixed to one end of the main drive roller **480** and a gear train including one or more drive gears **486** is used to transfer torque from the motor **483** to the main drive roller **480**. In this example, the gear train includes a single drive gear **486** which is affixed to a shaft of the motor **483**. However, in other embodiments, more than one drive gear **486** can be included in the gear train between the motor **483** and the driven gear **485**. For the same reasons that were discussed earlier with respect to the diameters of the web-transport rollers, it is desirable that each of the gears in these gear trains (e.g., driven gear **485** and drive gear **486**) should rotate substantially an integer number of times as the web of media **110** is advanced by the distance between two successive print locations. This can be achieved by proper design of the gear ratio between the driven gear **485** on the main drive roller **480** and each of the drive gears **486**. Assuming that the main drive roller **480** is designed to satisfy the aforementioned design criteria that its circumference be equal to an integer fraction of the span between two successive print locations, constraining the gear ratios of the gears such that they rotate an integer number of times for each rotation of the main drive roller **480** will provide the desired result. For example, if the main drive roller **480** has a circumference which is one third of span between two successive print locations, the main drive roller **480**, and therefore the driven gear **485**, will rotate 3× as the web of media **110** is advanced from one print location to the next. And if the driven gear **485** has the same number of teeth as the drive gear **486** (i.e., a 1:1 gear ratio), the drive gear **486** will rotate at the same rate as the driven gear **485**, and will therefore also rotate 3× as the web of media **110** is advanced from one print location to the next. In some embodiments, there may be a plurality of driven rollers (e.g., drive rollers **366**, **368** in FIG. **8**). In such cases, this design criterion is preferably applied to all gears associated with all of the driven rollers. Preferably this design criterion is satisfied to within 1%, and more preferably is satisfied to within 0.1%.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

100 printing system
104 media advance direction
106 marking element array direction
110 web of media
111 supply roll
112 take-up roll
115 web transport path
116 first side
117 second side
120 printhead
120*a* printhead
120*b* printhead
120*c* printhead
120*d* printhead
121 print line
121*a* print line
121*b* print line
121*c* print line
121*d* print line
123 printhead module
124 marking element array
130 support structure
131 print line roller
133 support roller
135 span extension roller
139 surface
140 dryer
141 dryer roller
145 quality control sensor
150 printing module
151 first zone
152 second zone
160 controller
200 inkjet printing system
205 inkjet printing system
220 printhead
220*a* printhead
220*b* printhead
220*c* printhead
220*d* printhead
221 print line
222 print line
223 printhead module
224 nozzles
225*a* inkjet nozzle array
225*b* inkjet nozzle array
225*c* inkjet nozzle array
226*a* inkjet nozzle array
226*b* inkjet nozzle array
226*c* inkjet nozzle array
230 support structure
239 surface
240*a* printhead
240*b* printhead
240*c* printhead
240*d* printhead
250 printing module
300 inkjet printing system
309 exit direction
355 first printing module
360 turnover mechanism
365 second printing module
366 drive roller
367 nip roller
368 drive roller
369 nip roller
400 inkjet printing system
460 media-guiding subsystem
461 web transport roller
462 web transport roller
470 S-wrap tensioning subsystem
471 web transport roller
475 load cell roller
480 main drive roller
481 web transport roller
482 web transport roller
483 motor
485 driven gear
486 drive gear
C_R roller circumference
L span
L_{ab} span
L_{bc} span
L_{cd} span
M integer
N integer
N_1 integer
N_2 integer
N_3 integer
R non-printing region
S speed
V overlap region
W spacing distance
W_e extended spacing distance
Δt timing delay

The invention claimed is:

1. A printing system for printing on a web of media traveling along a web transport path, comprising:
a plurality of printheads for printing on the web of media, each of the printheads being configured to print at one or more corresponding print locations along the web transport path;
a plurality of web transport rollers to guide the web of media along the web transport path;
one or more drive rollers for causing the web of media to move along the web transport path, the drive rollers having an affixed driven gear driven by a motor using a gear train including one or more drive gears which transfer torque from the motor to the driven gear;
wherein the driven gear and the drive gears associated with the drive rollers are constrained to rotate substantially an

integer number of times as the web of media is advanced along the web transport path between two successive print locations.

2. The printing system of claim **1**, wherein one of the drive gears is affixed to a shaft on the motor.

3. The printing system of claim **1**, wherein the rotation of driven gear and the drive gears as the web of media is advanced along the web transport path between two successive print locations is within 1.0% of being an integer.

4. The printing system of claim **1**, wherein the rotation of driven gear and the drive gears as the web of media is advanced along the web transport path between two successive print locations is within 0.1% of being an integer.

5. The printing system of claim **1**, wherein the drive rollers are constrained to have a roller circumference that is substantially equal to an integer fraction of a span of the web of media along the web transport path between two successive print locations.

6. The printing system of claim **1**, wherein at least some of the web transport rollers are constrained web transport rollers that are constrained to have a roller circumference that is substantially equal to an integer fraction of a span of the web of media along the web transport path between two successive print locations.

7. The printing system of claim **6**, wherein each of the constrained web transport rollers has the same roller circumference.

8. The printing system of claim **6**, wherein all of the web transport rollers located along the web transport path between successive print locations are constrained web transport rollers.

9. The printing system of claim **6**, wherein the web of media travels along the web transport path from a supply roll to a take-up roll, and wherein at least one of the constrained web transport rollers is located along the web transport path between the supply roll and a first print location.

10. The printing system of claim **9**, further including a front-end motion isolation mechanism located along the web transport path between the supply roller and the first print location, and wherein all of the web-transport rollers located along the web transport path between the front-end motion isolation mechanism and the first print location are constrained web-transport rollers.

11. The printing system of claim **6**, wherein the web of media travels along the web transport path from a supply roll to a take-up roll, and wherein at least one of the constrained web transport rollers is located along the web transport path between a last print location and the take-up roll.

12. The printing system of claim **11**, further including a back-end motion isolation mechanism located along the web transport path between the last print location and the take-up roller, and wherein all of the web-transport rollers located along the web transport path between the last print location and the back-end motion isolation mechanism are constrained web-transport rollers.

13. The printing system of claim **6**, wherein the printing system has first, second and third print locations arranged successively along the web transport path, and wherein a first span of the web of media between the first and second print locations is different than a second span of the web of media between the second and third print locations.

14. The printing system of claim **13**, wherein the roller circumference of the constrained web transport rollers is substantially equal to integer fractions of both the first span of the web of media and the second span of the web of media.

15. The printing system of claim **6**, wherein the roller circumference is equal to an integer fraction of a span of the web of media along the web transport path between two successive print locations to within 1.0%.

16. The printing system of claim **6**, wherein the roller circumference is equal to an integer fraction of a span of the web of media along the web transport path between two successive print locations to within 0.1%.

17. The printing system of claim **1**, wherein the printing system is an inkjet printing system and the printheads are inkjet printheads.

18. The printing system of claim **1**, wherein at least one of the printheads prints on a first side of the web of media, and at least one of the printheads prints on an opposing second side of the web of media.

19. The printing system of claim **1**, wherein at least one of the printheads includes:

a first group of marking elements arranged along a first print line; and

a second group of marking elements arranged along a second print line, the second print line being spaced apart from the first print line along a media advance direction, such that the first print line and the second print line correspond to successive print locations.

20. The printing system of claim **1**, wherein the plurality of web transport rollers includes a first print line roller aligned with the first print line, and a second print line roller aligned with the second print line, and wherein the first and second print line rollers are constrained web transport rollers that are constrained to have a roller circumference that is substantially equal to an integer fraction of a span of the web of media along the web transport path between the first print line and the second print line.

21. The printing system of claim **20**, further including a span extension member disposed along the web transport path between the first print line roller and the second print line roller for increasing the span of the web of media along the web transport path between the first print line and the second print line.

22. The printing system of claim **21**, wherein the span extension member is a constrained web transport roller.

23. The printing system of claim **1**, further including a controller which adjusts a position that image data is printed by a particular printhead on a line-by-line basis according to a correction function, wherein the correction function is determined by characterizing registration errors as a function of position within an image frame.

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